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# Diversity and dynamics of microarthropods from different biotopes of Las Sardinas cave (Mexico)

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ABSTRACT

An ecological study of the microarthropod communities from Las Sardinas cave was undertaken. Four different biotopes were studied over the course of a year: bat guano, litter, soil under the chemoautotrophic bacteria colonies and as a control, plain soil without litter or guano. A total of 27,913 specimens of a total of 169 species were collected. Analysis of Variance (ANOVA) showed that there is a significant effect of biotope on the recorded density, and the post hoc Tukey's test showed that guano is the most different biotope with the highest value of density recorded. The interaction between season and biotope variables was not significant. In the most extreme case, 99 percent of the microarthropods in soil under chemoautotrophic bacteria were mites, mainly in the family Histiostomidae.

Key words: Cave communities, distribution, energy fluxes, food resources, microarthropods

## INTRODUCTION

Caves are environments with relatively stable climatic conditions, compared to those outside. This environment is characterized by the lack of light and very often limited food resources, usually coming from the outside, via streams, gravity, feces of animals or their own remains. But those with big populations of bats can produce large amounts of guano that in many cases are used as fertilizer.

Most animals living inside caves, were considered as "cavernicolous" (Barr 1963), and others as accidental. Among cavernicoles there are trogloxenes, troglophiles or troglobites according to their life cycle, in agreement to Schinner-Racovitza classification (Racovitza 1907). The number of species living exclusively in the subterranean environments has been estimated between 50,000 and 100,000 (Culver and Holsinger 1992), and the invertebrates, mainly arthropods, constitute the majority of cave animals (Gibert and Deharveng 2002).

Springtails (Collembola) and mites (Acari) are the most diverse and abundant microarthropods in soils and other subterranean environments. They play such an important role in the trophic webs that some authors consider them as the "subterranean plankton" (Ginet and Decou 1977). The movements and dispersion routes of this fauna have been better understood after the discovery of the "milieu souterrain superficiel" (Juberthie et al. 1981). The vertical migration of the animals from surface to caves has been also explained thanks to their transportation through the microcaves of the superficial environment, and the movement of carbon from the soil to the superficial subterranean environment (Gers 1998). The most important energy flow in caves is input of particulate organic carbon or dissolved organic carbon in water (Simon and Benfield 2001; Simon et al. 2007).

The vast geologic diversity of Mexico makes it very interesting for speleological studies. About 20% of the Mexican territory is karst and more than 1,200 caves have been recorded, and some are among the deepest caves of the World (Lazcano 1983, Espinasa 1990, Arias 2001).

Therefore, Mexico is very attractive for biospeleological research. There is a rich cave fauna and their representatives present interesting adaptations for this peculiar environment. Compilation of all the information about the Mexican fauna has been done by Reddell (1981) and Hoffmann et al. (2004). The most interesting species for their adaptation to cave life were listed by Palacios-Vargas (1994).

The State of Tabasco, which is located in the South of Mexico, is a region with well developed karst (Espinasa 1990), and the fauna of 14 Tabascan caves have been recorded (Reddell 1981). Cueva de Las Sardinas is located on "Villaluz" Ranch, in a small relict of what was once a rich tropical rain forest. Villaluz Ranch is located about two kilometers from Tapijulapa town, in Southeastern Mexico.

The first scientific record about this cave dates back to 1944, when Stirling collected flatworms of the genus *Dugesia,* fish of genus *Poecilia,* trichodactylid crabs of

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the species *Trichodactylus bidens,* one amblypigid of the genus *Phrynus,* several genera of spiders such as *Tetragnatha, Maymena* and *Eidmanella,* and one hemipteran of the genus *Belostoma.*

Gordon and Rosen (1962) made a systematic study about the fishes from Las Sardinas and their adaptations to cave life. They also cited three species of bats: *Mormoops megalophylla* Peters, *Pteronotus davyi* Gray and *Pteronotus parnellii* Gray. In 1998, Gamboa and Kú made the first topographical description of the cave and gave a list of the surroundings vegetation. Mejía and Palacios-Vargas (2001) collected 31 specimens of *Poecilia sphenops,* among which there was a pregnant female with 15 embryos. Stomach contents of those specimens were analyzed and some arthropods and plant remains were observed. They also recorded ostracods (possible *Cyclocypris*) and one crab *(Avotrichodactylus bidens* Bott*).*

Hose and Pisarowicz (1999) made a complete and detailed description of this cave which included a map. The importance of Las Sardinas, as a special environment was pointed out by Hose (1999) who described several of the bacteria living there. The bacteria described by Hose and Pisarowicz (1999) are chemoautotrophic, and the secretions of their colonies were called "snottites" because of their appearance. Chemoautotrophic bacteria survive without sunlight, and take energy from an exothermic reaction, in which sulfihidric acid is broken down into sulfuric acid. The products of this natural reaction increase the erosion of cave walls. This process was named "replacement solution" by Egeimer (1981). This process produces deposition of the sulfur and gypsum on the walls and ceiling of the cave which are very heavy and weak, and easily crumbles and is dissolved by water very quickly.

The sulfur-eating bacteria constitute the base of the food webs. This was discovered for the first time in the Movile cave in Romania, where the ecosystem is chemoautotrophically based (Sarbu and Popa 1992, Sarbu et al. 1996). The difference of Movile cave and Cueva de Las Sardinas is that the Mexican cave has three different supplies of energy: guano from the bat colonies, litter and other detritus which fall through the different skylight holes (originated by the action of acids) and the "snottites", the bacteria colonies. Movile was a closed old system and Las Sardinas is a relatively new and open system.

Several studies of arthropods in Las Sardinas cave have been done, but they are mainly taxonomic (Estrada and Iglesias 2003; Estrada and Mejía-Recamer 2005; Palacios-Vargas and Estrada 2003; Palacios-Vargas et al. 2009) or morphological (Fuentes et al. 2007), but very few of them are related to communities and dynamics. This study mainly focuses on communities and the position of different groups in the complex food chains or trophic web existing in the cave. The study was done during one year and allowed us to make an inventory of the fauna living in this cave.

## MATERIALS AND METHODS

Four different biotopes, including the control biotope were studied in the cave for terrestrial communities, which were chosen in twelve different chambers along the cave. They were: a) bat guano; b) litter, debris with soil associate to skylights; c) soil under bacteria colonies; d) soil as control, principally limestone (Fig. 1).

The sampling was done every three months, from March 2001 to March 2002. Twelve samples were taken each time (one from each chamber), every sample was about 600 cm$^3$ and all of them were put in plastic boxes and taken to the laboratory. In the laboratory the samples were processed by Berlese-Tullgren funnels to extract the microarthropod specimens. Specimens were stored in

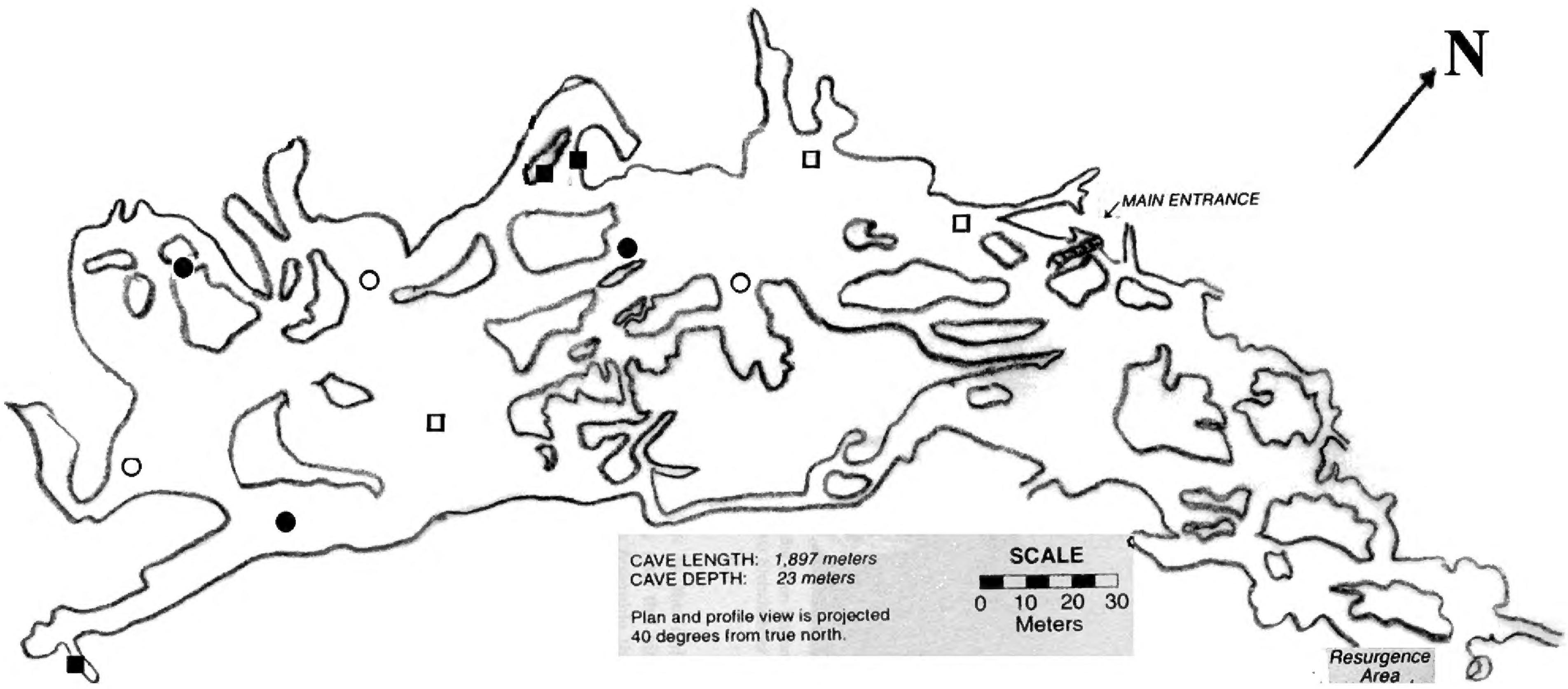


Fig. 1 - Map of the Las Sardinas cave with the location of the samples stations. ■ Bat guano, □ Litter, ● Soil under bacteria colonies and ○ Soil control (Map modified from Hose et al. 2000)

75% alcohol. After that, they were isolated by morphospecies and counted in order to obtain the abundance and the diversity index for each season of the year. For the identification, many specimens of each morphotype were cleared and mounted in Hoyer's solution.

Species richness (S), Shannon diversity ($H' = \Sigma p_i \ln p_i$) and Pielou´s evenness ($J' = H'/\ln S$) indices were calculated. Diversity index were compared between pairs with a t test modified (Magurran 1988; Zar 1984), using PAST software (Hammer et al. 2001). An analysis of variance (ANOVA) was used to evaluate the effect of biotope and that of the season on the density of microarthropods. The affinity of the species to the biotopes was studied with cluster analysis, using the dissimilarity rate (difference between two percentage distributions) as a distance and graphically represented using UPGMA as the aggregation method. All analyses were performed using STATISTICA 5.0 software (Statsoft 1996).

According to the available bibliographic information about the biology of the spotted species, the feeding relationships were inferred in order to show the potential trophic relationships in the cave. In some cases information observed in field on feeding behavior was recorded, as well the gut content observed in slides preparations of microarthropods.

## RESULTS AND DISCUSSION

A total of 27,913 specimens were collected (Table 1). The largest number was taken from guano (21,422; 7 individuals $m^{-3}$), followed by litter (4,455; 1.5 individuals $m^{-3}$), the soils with the bacteria colonies (1,614; 0.5 individuals $m^{-3}$) and control soil (422; 0.1 individuals $m^{-3}$). ANOVA (Table 2) showed a significant effect of the biotope upon the microarthropod density ($F_{3,40} = 25.67$, $p<0.0001$), the *post hoc* Tukey test ($p<0.001$) showed that guano differs from the others biotopes in the density of organisms (Table 3). The interaction between season and biotope variables was not significant, that means that the arthropod density does no change depending on the biotope according to the date (Date: $F_{4, 40} = 0.60$, $p>0.05$; interaction: $F_{12, 40} = 1.25$, $p>0.05$).

Twenty-four microarthropod species were found in soil under the bacteria colonies, forty-four in the control soil, fifty-seven in the guano and one hundred and thirty-six in the litter. The total number of species of this cave was 169. The variation in the number of species in each biotope through the year is shown in Fig. 2.

The most important results of our studies are: 99% of the microarthropods in soil under the chemoautotrophic bacteria colonies were mites, 80% belongs to the cohort Astigmatina (mainly family Histiostomidae), 15% to the Oribatei (mainly family Oppiidae) and only 4% of order Mesostigmata. The remaining arthropods were mainly pseudoscorpions and spiders.

In the control soil, the mites represent 81% microarthropods; among them 38% are Astigmatina (also mainly of the family Histiostomidae). Then, the order Trombidiformes is represented by 22% (mainly the predatory family Cunaxidae) and the other groups are similar to those in the soil under the chemoautotrophic bacteria.

The litter has the highest diversity of microarthropods, but mites are again the dominant group (79%). Among mites, Astigmatina represent 43%, but one important difference is that there were at least 15 morphospecies of Oribatei and 12 of Mesostigmata, almost twice the number found in the other biotopes. Collembola oc-

Table 1 - Abundance of microarthropods, by biotope, found on "Las Sardinas" cave. Trophic groups: B = Bacteriophagous; D = Depredator; F = Phytophagous; L = Litter feeder (Panphytophagous); M = Mycophagous; N = Nematophagous; O = Omnivorous; P = Parasite; S = Scavenging; ND = No Determinate.

| Phylum Arthropoda | Litter | Bat Guano | Soil under bacteria colonies | Soil control | Trophic Group | Feeding habit reference |
|---|---|---|---|---|---|---|
| Class Arachnida | | | | | | |
| Order Pseudoscorpiones | 2 | 7 | 11 | 17 | D | De Andrade and Gnaspini 2002 |
| Family Chernetidae | 6 | | | | D | Johnson and Wellington 1980 |
| *Cordylochernes* sp. | | 247 | | | D | Taxa generalized |
| *Lustrochernes* sp. | | 19 | | | D | Taxa generalized |
| Family Lechytiidae | | | | | | |
| *Lechytia* sp. | | 2 | | | D | Taxa generalized |
| Family Olpiidae | | | 1 | | D | Taxa generalized |
| Family Syarinidae | | | | | | |
| *Ideoblothrus* sp. | 10 | | 1 | 4 | D | Taxa generalized |
| Order Schizomida | 2 | | | | D | Taxa generalized |

| Phylum Arthropoda | Litter | Bat Guano | Soil under bacteria colonies | Soil control | Trophic Group | Feeding habit reference |
|---|---|---|---|---|---|---|
| Order Araneae | | | | | | |
| Family Dipluridae | 2 | 2 | | | D | Jiménez 1998 |
| Family Linyphiidae | 19 | | | | D | Harwood et al. 2001 |
| Family Mimetidae | 6 | | | | D | Kloock, 2001 |
| Family Pholcidae | 3 | 1 | | | | Jiménez 1998 |
| Family Salticidae | 27 | | 3 | 19 | D | Jiménez 1998 |
| Order Opilionida | 1 | | | | D | Santos and Gnaspini 2002 |
| Subclass Acari | | | | | | |
| Order Ixodida | | | | | | |
| Superfamily Ixodoidea | | | | | | |
| Family Ixodidae | 1 | | | | P | Taxa generalized |
| Family Argasidae | | | | | | |
| *Antricola* sp. | 7 | 43 | | | C, P | De la Cruz and de Armas 1990 |
| Order Mesostigmata | | | | | | |
| Morphospecies 1 | 9 | | | | ND | |
| Morphospecies 2 | 1 | | | | ND | |
| Morphospecies 3 | 6 | | | 2 | ND | |
| Suborder Sejida | | | | | | |
| Superfamily Sejoidea | | | | | | |
| Family Sejidae | | | | | | |
| *Sejus* sp. | | 11 | 67 | 19 | D | Walter and Proctor 1998 |
| Suborder Trigynaspida | | | | | | |
| Cohort Antennophorina | | | | | | |
| Superfamily Celanopsoidea | | | | | | |
| Family Diplogyniidae | | 6 | | | F | Hunter 1993 |
| Superfamily Megisthanoidea | | | | | | |
| Family Megisthanidae | 3 | | | | F, N | Hunter 1993 |
| Suborder Monogynaspida | | | | | | |
| Cohort Uropodina | | | | | | |
| Subcohort Uropodiae | | | | | | |
| Superfamily Uropodoidea | 1 | | | | L, H | Nawar et al. 1993 |
| Family Metagynuridae | | | | | | |
| *Metagynella* sp. | | 13 | | 5 | L | Taxa generalized |
| Family Uropodidae | | | | | | |
| *Uropoda* (*Phaulodinychus*) sp. | 11 | 12931 | | | L | Vazquez and Klompen 2007 |
| Family Trematuridae | | | | | | |
| *Trichouropoda* sp. | | 21 | | | L, M | Lindquist et al. 2009 |
| Cohort Gamasina | | | | | | |
| Subcohort Dermanyssiae | | | | | | |
| Superfamily Rhodacaroidea | | | | | | |
| Family Ologamasidae | | | | | | |
| *Gamasellus* sp. | 1 | 1 | | 1 | D | Lister et al. 1998 |
| Family Rhodacaridae | | | | | | |
| *Rhodacarus minimus* | 81 | | | | D, N | Sardar and Murphy 1987 |
| Superfamily Eviphidoidea | | | | | | |
| Family Macrochelidae | | | | | | |
| *Glyptholaspis* sp. | | 392 | | 7 | D | Lindquist et al. 2009 |
| Superfamily Ascoidea | | | | | | |
| Family Ascidae | | | | | | |
| *Gamasellodes* sp. | 1 | 1424 | 2 | | D, N | Walter 1987[a] |

| Phylum Arthropoda | Litter | Bat Guano | Soil under bacteria colonies | Soil control | Trophic Group | Feeding habit reference |
|---|---|---|---|---|---|---|
| Family Melicharidae | | | | | | |
| *Proctolaelaps* sp. | | | 1 | | D | Lindquist et al. 2009 |
| Superfamily Phytoseioidea | | | | | | |
| Family Blattisociidae | | | | | | |
| *Lasioseius* sp. | 199 | | | 6 | D, M, N | Walter and Lindquist, 1989 |
| Family Phytoseiidae | | 140 | | | D | McMurtry and Croft 1997 |
| Superfamily Dermanyssoidea | | | | | | |
| Family Laelapidae | | | | | | |
| *Gaeolaelaps* sp. | 47 | 5 | | | D, N | Walter and Oliver 1989 |
| *Hypoaspis* sp. | 4 | | | | D | Taxa generalized |
| Family Macronyssidae | | | | 1 | P | O'Connor 1998 |
| Order Trombidiformes | | | | | | |
| Morphospecies 1 | 3 | 1 | | 4 | ND | |
| Morphospecies 2 | 2 | 1 | | | ND | |
| Morphospecies 3 | 20 | | | | ND | |
| Morphospecies 4 | 1 | | | | ND | |
| Morphospecies 5 | 1 | | | | ND | |
| Morphospecies 6 | | | | 1 | ND | |
| Suborder Prostigmata | | | | | | |
| Supercohorte Eupodides | | | | | | |
| Superfamily Bdelloidea | | | | | | |
| Family Cunaxidae | | | | | | |
| *Coleoscirus* ca. *breslauensis* | 22 | 10 | 2 | 3 | D, N | Walter and Kaplan 1991 |
| *Coleoscirus* ca. *simplex* | 9 | | | 1 | D, N | Walter and Kaplan 1991 |
| *Cunaxoides* ca. *nicobarensis* | 3 | | | | D | Fain et al. 1993 |
| *Cunaxoides* sp. | 16 | 654 | | | D | Fain et al. 1993 |
| *Dactyloscirus* sp. 1 | 4 | | 15 | 25 | D | Taxa generalized |
| *Dactyloscirus* sp. 2 | 6 | | 1 | | D | Taxa generalized |
| *Neoscirula* ca. *luxtoni* | 4 | | | | D | Taxa generalized |
| *Neoscirula* ca. *delareyi* | 1 | | | | D | Taxa generalized |
| *Neoscirula* sp. | 6 | | 1 | 18 | D | Taxa generalized |
| *Pseudobonzia* sp. | 39 | | 1 | 4 | D | Taxa generalized |
| *Pulaeus* ca. *pectinatus* | 1 | | | | D | Taxa generalized |
| *Pulaeus* sp. 1 | 10 | 616 | | 3 | D | Taxa generalized |
| *Pulaeus* sp. 2 | 29 | 7 | | | D | Taxa generalized |
| Superfamily Eupodoidea | | | | | | |
| Family Rhagidiidae | | | | | | |
| *Robustocheles* sp. | 1 | | | | D | Taxa generalized |
| Supercohort Trombidiae | | | | | | |
| Superfamily Trombidioidea | | 13 | | 1 | | Azevedo et al. 2002 |
| Superfamily Trombiculoidea | | | | | | |
| Family Neotrombidiidae | | 2 | | | P | Taxa generalized |
| Supercohort Eleutherengonides | | | | | | |
| Cohort Heterostigmatina | | | | | | |
| Superfamily Tarsonemoidea | | | | | | |
| Family Tarsonemidae | 2 | 2 | | | L, F | Estebanes-Gonzalez 1997 |
| Order Sarcoptiformes | | | | | | |
| Suborder Endeostigmata | | | | | | |
| Cohort Alycina | | | | | | |
| Superfamily Alycoidea | | | | | | |
| Family Nanorchestidae | 31 | | | 11 | L, M | Walter 1987b |
| Suborder Oribatida | | | | | | |

| Phylum Arthropoda | Litter | Bat Guano | Soil under bacteria colonies | Soil control | Trophic Group | Feeding habit reference |
|---|---|---|---|---|---|---|
| Supercohort Palaesomatides | | | | | | |
| Superfamily Palaeacaroidea | 2 | | | | L | Taxa generalized |
| Supercohort Enarthronotides | | | | | | |
| Superfamily Hypochthonioidea | | | | | | |
| Family Lohmanniidae | | | | | | |
| *Javacarus* (*Euryacarus) pilosus* | 6 | | | | L | Taxa generalized |
| Supercohort Mixonomatides | | | | | | |
| Superfamily Euphthiracaroidae | | | | | | |
| Family Euphthiracaridae | 1 | | | | L | Taxa generalized |
| Superfamily Phthiracaroidae | | | | | | |
| Family Phthiracaridae | 13 | | | | L | Taxa generalized |
| Supercohort Desmonomatides | | | | | | |
| Cohort Nothrina | | | | | | |
| Superfamily Crotonioidea | | | | | | |
| Family Malaconothridae | | | | | | |
| *Malaconothrus* ca. *angulatus* | 1 | | | | L | Palacios-Vargas and Iglesias 1997 |
| *Malaconothrus* ca. *pervensis* | 5 | | | | L | Palacios-Vargas and Iglesias 1997 |
| *Malaconothrus* ca. *granulosus* | 27 | | | | L | Palacios-Vargas and Iglesias 1997 |
| *Malaconothrus* (*Cristonothrus*) *peruanensis* | 29 | | | | L | Palacios-Vargas and Iglesias 1997 |
| *Malaconothrus* sp. | | 3 | | | L | Palacios-Vargas and Iglesias 1997 |
| Cohort Brachypylina | | | | | | |
| Superfamily Microzetoidea | | | | | | |
| Family Microzetidae | | | | | | |
| *Berlesezetes brazilozetoides* | 1 | | | | L | Taxa generalized |
| Superfamily Gustaviodea | | | | | | |
| Family Liacaridae | | | | | | |
| *Cultroribula* sp. | 1 | | | | L | Taxa generalized |
| Superfamily Carabodoidea | | | | | | |
| Family Carabodidae | | | | | | |
| *Cubabodes* ca. *radiatus* | 39 | | | | L | Taxa generalized |
| Family Dampfiellidae | | | | | | |
| *Beckiella* sp. | 1 | | | | L | Taxa generalized |
| Superfamily Oppioidea | | | | | | |
| Family Oppiidae | | | | | | |
| Subfamily Oppiinae | | | | | | |
| *Aeroppia* ca. *nasalis* | 3 | | | | L | Taxa generalized |
| *Aeroppia nasalis* | 11 | | | | L | Taxa generalized |
| *Aeroppia* sp. | | | | 1 | L | Taxa generalized |
| *Amerioppia similis* | 37 | | | 2 | L | Taxa generalized |
| *Taiwanoppia* (*Vietoppia*) sp. | 1 | | | | L | Taxa generalized |
| Subfamily Multioppiinae | | | | | | |
| *Intermedioppia* ca. *alvarezi* | 136 | | 250 | 111 | L | Guevara et al. 2002 |
| Subfamily Mystroppinae | 6 | | | 2 | L | Taxa generalized |
| Subfamily Arcoppiinae | | | | | | |
| *Similoppia (Reductoppia)* sp. | | 2 | | | L | Subias and Rodriguez 1987 |

| Phylum Arthropoda | Litter | Bat Guano | Soil under bacteria colonies | Soil control | Trophic Group | Feeding habit reference |
|---|---|---|---|---|---|---|
| Family Suctobelbidae | | | | | | |
| *Suctobelbella* (*Flagrosuctobella*) *multiplumosa* | 1 | | | | L | Taxa generalized |
| Superfamily Oriopodoidea | | | | | | |
| Family Haplozetidae | | | | | | |
| *Trachyoribates* (*Rostrozetes*) *foveolatus* | 420 | 453 | | | L | Taxa generalized |
| Family Scheloribatidae | | | | 1 | L, M | Hubert et al. 2000 |
| *Scheloribates elegans* | 22 | | | | L, M | Hubert et al. 2000 |
| *Scheloribates* sp. | 95 | 1 | | | L, M | Hubert et al. 2000 |
| Superfamily Ceratozetoidea | | | | | | |
| Family Ceratozetidae | | | | | | |
| *Ceratozetes* sp. | 2 | | | | L, M | Walter 1987b |
| Superfamily Galumnoidea | | | | | | |
| Family Galumnidae | | | | | | |
| *Galumna* ca. *hamifer* | 66 | | | | L | Schatz 1998 |
| *Galumna hamifer* | 23 | | | | L | Schatz 1998 |
| Cohort Astigmatina (Astigmata) | | | | | | |
| Superfamily Histiostomatoidea | | | | | | |
| Family Guanolichidae | | | | | | |
| *Neoguanolichus* sp. | 7 | 802 | 866 | 3 | C | Fain 1979 |
| Family Histiostomatidae | | | | | | |
| *Histiostoma* ca. *himalayae* | | | | 5 | B | Vreeken-Bujin et al. 1997 |
| *Histiostoma* ca. *bakeri* | 25 | | | | B | Vreeken-Bujin et al. 1997 |
| *Histiostoma* ca. *piloseta* | | 1209 | | | B | Vreeken-Bujin et al. 1997 |
| *Histiostoma* ca. *sextoni* | 293 | | | | B | Vreeken-Bujin et al. 1997 |
| *Histiostoma* sp. 1 | 699 | 367 | 114 | 57 | B | Vreeken-Bujin et al. 1997 |
| *Histiostoma* sp. 2 | 5 | | | | B | Vreeken-Bujin et al. 1997 |
| *Histiostoma* sp. 3 | 1 | | | | B | Vreeken-Bujin et al. 1997 |
| *Histiostoma* sp. 4 | 109 | | | 5 | B | Vreeken-Bujin et al. 1997 |
| Superfamily Hemisarcoptoidea | | | | | | |
| Family Winterschmidtiidae | | | | | | |
| *Winterschmidtia* sp. | | 2 | | | F | Rodriguez-Navarro et al. 2003 |
| Superfamily Glycyphagoidea | | | | | | |
| Family Rosensteiniidae | | | | | | |
| *Nycteriglyphagus* sp. | 4 | 8 | | | L | OConnor 1998 |
| Superfamily Acaroidea | | | | | | |
| Family Acaridae | | | | | | |
| *Rhizoglyphus* ca. *callae* | 130 | 2 | | 1 | F | Díaz et al. 2000 |
| *Rhizoglyphus* ca. *robini* | 59 | 1 | | | F, N | Estebanes-Gonzalez & Rodriguez-Navarro 1991 |
| *Sancassania* ca. *mycophagus* | 7 | 126 | 262 | 24 | F | Estebanes-Gonzalez & Rodriguez-Navarro 1991 |
| *Schwiebea* sp. | 737 | 1 | 22 | 6 | M | Okabe 1999 |
| *Tyrophagus* ca. *neiswanderi* | 10 | 1 | | 1 | M | Okabe 1999 |
| *Tyrophagus* ca. *similis* | | 1 | | | F, M | Okabe 1999 |
| Class Crustacea | | | | | | |
| Subclass Copepoda | | | | | | |
| Order Harpacticoida | 34 | | | | B | Rieper 1978 |
| Order Isopoda | 10 | | | | L | Reeves and McCreadie 2001 |

| Phylum Arthropoda | Litter | Bat Guano | Soil under bacteria colonies | Soil control | Trophic Group | Feeding habit reference |
|---|---|---|---|---|---|---|
| Class Collembola | | | | | | |
| Order Poduromorpha | | | | | | |
| Superfamily Neanuroidea | | | | | | |
| Family Neanuridae | | | | | | |
| Subfamily Neanurinae | | | | | | |
| *Americanura sardinasensis* | 28 | | | | L, M | Taxa generalized |
| Subfamily Pseudachorutinae | | | | | | |
| *Pseudachorutes* sp. | 7 | | | | L | Taxa generalized |
| *Neotropiella quinqueoculata* | 6 | | | | L, M | Taxa generalized |
| Family Odontellidae | | | | | | |
| *Xenyllodes* sp. | 1 | | | | L, M | Taxa generalized |
| Superfamily Hypogastruroidea | | | | | | |
| Family Hypogastruridae | | | | | | |
| *Ceratophysella* ca. *succinea* | 1 | | | 1 | L, M | Zettel et al. 2002 |
| *Xenylla* ca. *humicola* | | 17 | | 2 | L, M | Castaño-Meneses et al. 2004 |
| Superfamily Onychiroidea | | | | | | |
| Family Tullbergiidae | | | | | | |
| *Mesaphorura yosii* | 36 | | | 1 | L, M | Sabatini and Innocenti 2000 |
| Order Entomobryiomorpha | | | | | | |
| Superfamily Isotomoidea | | | | | | |
| Family Isotomidae | | | | | | |
| Subfamily Anurophorinae | | | | | | |
| *Cryptopygus* ca. *thermophilus* | 15 | | | | L, M | Castaño-Meneses et al. 2004 |
| *Cryptopygus thermophilus* | 20 | | | | L, M | Castaño-Meneses et al. 2004 |
| Subfamily Proisotominae | | | | | | |
| *Folsomina onychiurina* | 5 | | | | L, M | Taxa generalized |
| Subfamily Isotominae | | | | | | |
| *Isotoma* sp. | 18 | | | | L, M | Walter 1987b |
| *Isotomiella minor* | 9 | | | | L, M | Taxa generalized |
| *Isotomurus retardatus* | 15 | | | | L, M | Castaño-Meneses et al. 2004 |
| Superfamily Entomobryoidea | | | | | | |
| Family Entomobryidae | | | | 1 | L, M | Castaño-Meneses et al. 2004 |
| Subfamily Orchesellinae | | | | | | |
| *Heteromurus major* | 3 | | | | L, M | Scheu et al. 1999 |
| Subfamily Entomobryinae | | | | | | |
| *Entomobrya* sp. | 9 | | | | L, M | Chen et al. 1996 |
| Subfamily Lepidocyrtinae | | | | | | |
| *Lepidocyrtus* sp. | 1 | | | | L | Taxa generalized |
| *Pseudosinella* ca. *colina* | 2 | | | 1 | L, M | Walter 1987b |
| *Pseudosinella orba* | 7 | | | 7 | L, M | Walter 1987b |
| Family Paronellidae | | | | 2 | L | Taxa generalized |
| Order Neelipleona | | | | | | |
| Family Neelidae | | | | | | |
| *Megalothorax minimus* | 1 | | | | L | Taxa generalized |
| Order Symphypleona | | | | | | |
| Superfamily Katiannoidea | | | | | | |
| Family Katiannidae | | | | | | |
| *Sminthurinus quadrimaculatus* | | 2 | | | L | Taxa generalized |
| Family Arrhopalitidae | | | | | | |
| *Arrhophalites* sp. | 2 | | | | L | Taxa generalized |
| Superfamily Dicyrtomoidea | | | | | | |

| Phylum Arthropoda | Litter | Bat Guano | Soil under bacteria colonies | Soil control | Trophic Group | Feeding habit reference |
|---|---|---|---|---|---|---|
| Family Dicyrtomidae | | | | | | |
| Subfamily Ptenothricinae | | | | | | |
| *Ptenothrix marmorata* | 7 | | | | L | Taxa generalized |
| Class Symphyla | 1 | | | | L | Umble and Fisher 2003 |
| Class Insecta | | | | | | |
| Order Microcoryphia | | 1 | 1 | | L | Taxa generalized |
| Order Zygentoma | 1 | | | | L | Taxa generalized |
| Order Thysanoptera | | | | | | |
| *Adraneothrips* sp. | 6 | 1 | | | M | Childers et al. 1998 |
| *Zeugmatothrips priesneri* | 20 | | | | F, M | Taxa generalized |
| Order Psocoptera | 2 | | | | L, M | Taxa generalized |
| Order Hemiptera-Heteroptera | 1 | | | | F | Taxa generalized |
| Order Homoptera-Homoptera | 3 | 1 | 1 | 3 | L, F | Taxa generalized |
| Order Coleoptera | | | | | | |
| Larvae 1 | 19 | 416 | 2 | 8 | ND | |
| Larvae 2 | 337 | | | | ND | |
| Larvae 3 | | 6 | | | ND | |
| Family Curculionidae | 2 | | | | F | Navarrete-Heredia 2001 |
| Family Histeridae | | | | | | |
| *Hister* sp. | | 14 | | | N, D | Moreno et al. 1998 |
| Family Platypodidae | | 1 | | | F | Equihua-Martínez et al. 1984 |
| Family Ptiilidae | 1 | | | | L, M | Navarrete-Heredia 2001 |
| Family Scydmaenidae | 1 | 2 | 1 | 4 | D | OKeefe 2000 |
| Family Staphylinidae | 2 | | | | D | Leschen and Newton 2003 |
| *Anotylus* sp. | 6 | | | | L, N, M, S | Jimenez-Sanchez et al. 1990 |
| Order Lepidoptera | | 5 | | | F | Taxa generalized |
| Order Diptera | 9 | 22 | 2 | 3 | L | Taxa generalized |
| Larvae 1 | 9 | 227 | | | ND | |
| Larvae 2 | 19 | | | | ND | |
| Larvae 3 | 8 | 172 | | | ND | |
| Larvae 4 | 22 | 4 | | | ND | |
| Larvae 5 | 3 | | | | ND | |
| Family Chironomidae | | | | | | |
| Larvae 1 | 11 | 767 | | | L | Delettre 2000 |
| Order Hymenoptera | 1 | | | | F | Taxa generalized |
| Family Formicidae | | | | | | |
| Subfamily Amblyoponinae | | | | | | |
| *Prionopelta modesta* | 24 | | | | D | Taxa generalized |
| Subfamily Myrmicinae | | | | | | |
| *Leptothorax* sp. 1 | 18 | | | | O | Fernández 2001 |
| *Leptohtorax* sp. 2 | 10 | | | | O | Fernández 2001 |
| *Solenopsis* sp. 1 | 29 | | 1 | | D, O | Fernández 2001 |
| *Solenopsis* sp. 2 | 3 | | | | D, O | Fernández 2001 |
| *Strumigenys* sp. | 2 | | | | D | Fernández 2001 |
| *Tetramorium* sp. | 2 | | | | D | Bendicho and Gonzalez 1986 |
| *Wasmannia auropunctata* | 2 | | | | D | Taxa generalized |
| Subfamily Ponerinae | | | | | | |
| *Hypoponera* sp. | 12 | | | | | Taxa generalized |
| *Pachycondyla* sp. | 1 | | | | D | Dejean 1990 |

Table 2 - Results of ANOVA test to evaluate the effect of biotope and collecting date on the microarthropods density from Las Sardinas Cave, Tabasco Mexico. *p<0.05. N=40

| Source | F | Df | p |
|---|---|---|---|
| Biotope | 25.67 | 3 | 0.0001* |
| Date | 0.60 | 4 | 0.10 |
| Interaction | 1.25 | 12 | 0.20 |

Table 3 - Average density of microarthropods (ind/cm$^3$) from Las Sardinas Cave, Tabasco Mexico. Different letters denote differences according with *post hoc* Tukey's test.

| Biotope/Date | Average ±sd |
|---|---|
| Soil under bacteria colonies | 0.53±0.77a |
| Soil control | 0.14±0.08a |
| Litter | 1.48±0.99a |
| Bat Guano | 7.09±3.99b |

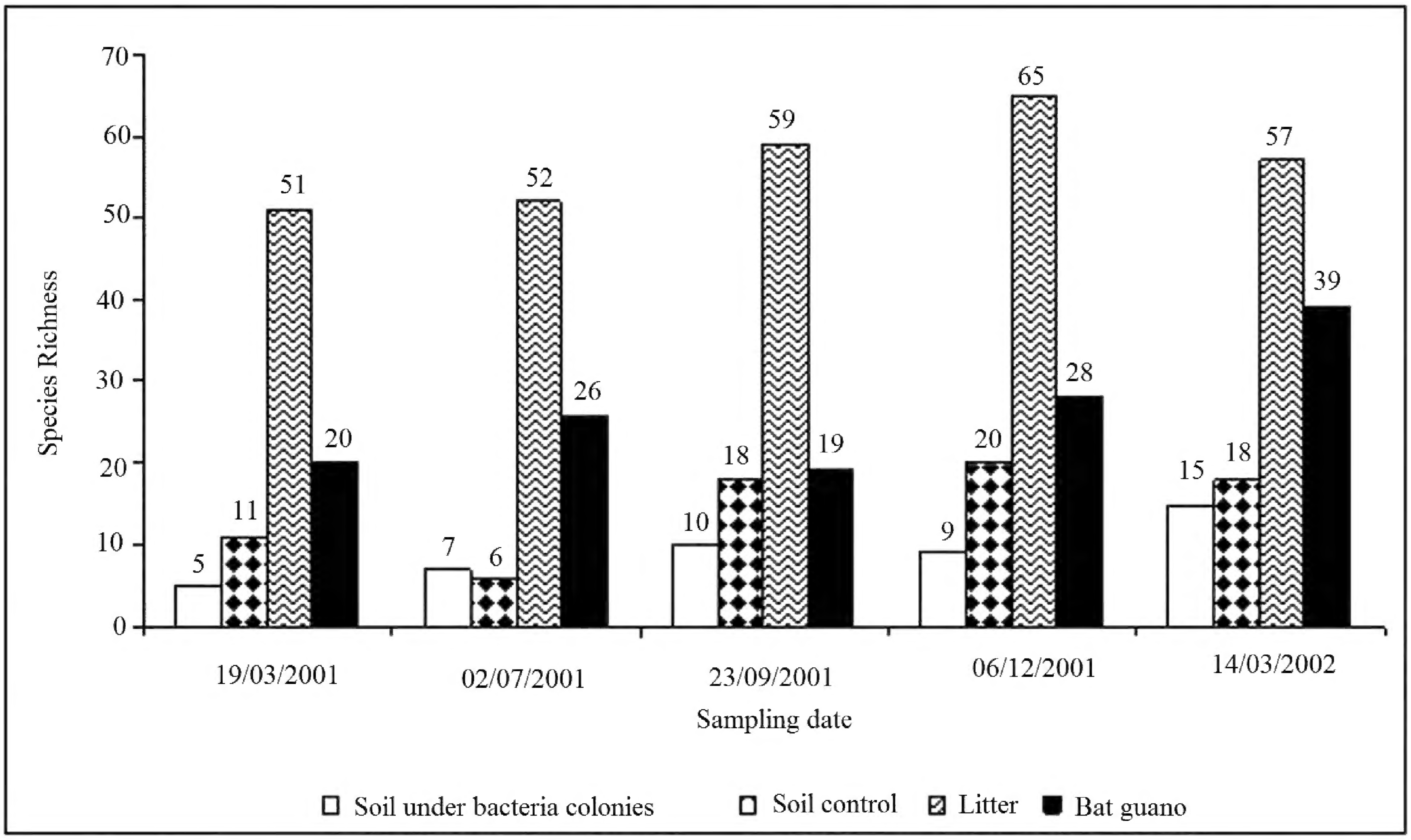


Fig. 2 - Number of species for each biotope at different dates in Las Sardinas cave, Tabasco, Mexico.

cupy the sixth place after three different species of mites and one of Coleopteran larvae.

Guano has high abundance of Mesostigmata mites (79% of total microarthropods), followed by Dipteran larvae and Astigmatid mites (6% each taxon), and the Trombidiformes (mainly Cunaxidae 3%). Figs 3 and 4 show the most abundant microarthropods from different biotopes in the cave.

There were important and statistical significant differences among the biotopes except between diversity of the litter and control soils. This suggests that the biotopes of this cave have four independent communities, in which the vegetal debris had the highest diversity according to the Shannon index (H'=3.34), followed by the control soil (H'=2.85), bat guano (H'= 1.72), and the soil under the bacteria (H'=1.43). The evenness follows more or less the same pattern, but the guano communities present the lowest value in evenness (J'=0.75 plant debris > 0.68 control soil > 0.45 bacteria > 0.43 guano). The guano probably has the lowest diversity because it has different fauna depending on maturation and the high abundance of few species. The t test results have shown significant differences between all the diversity indexes recorded in the study (Table 4).

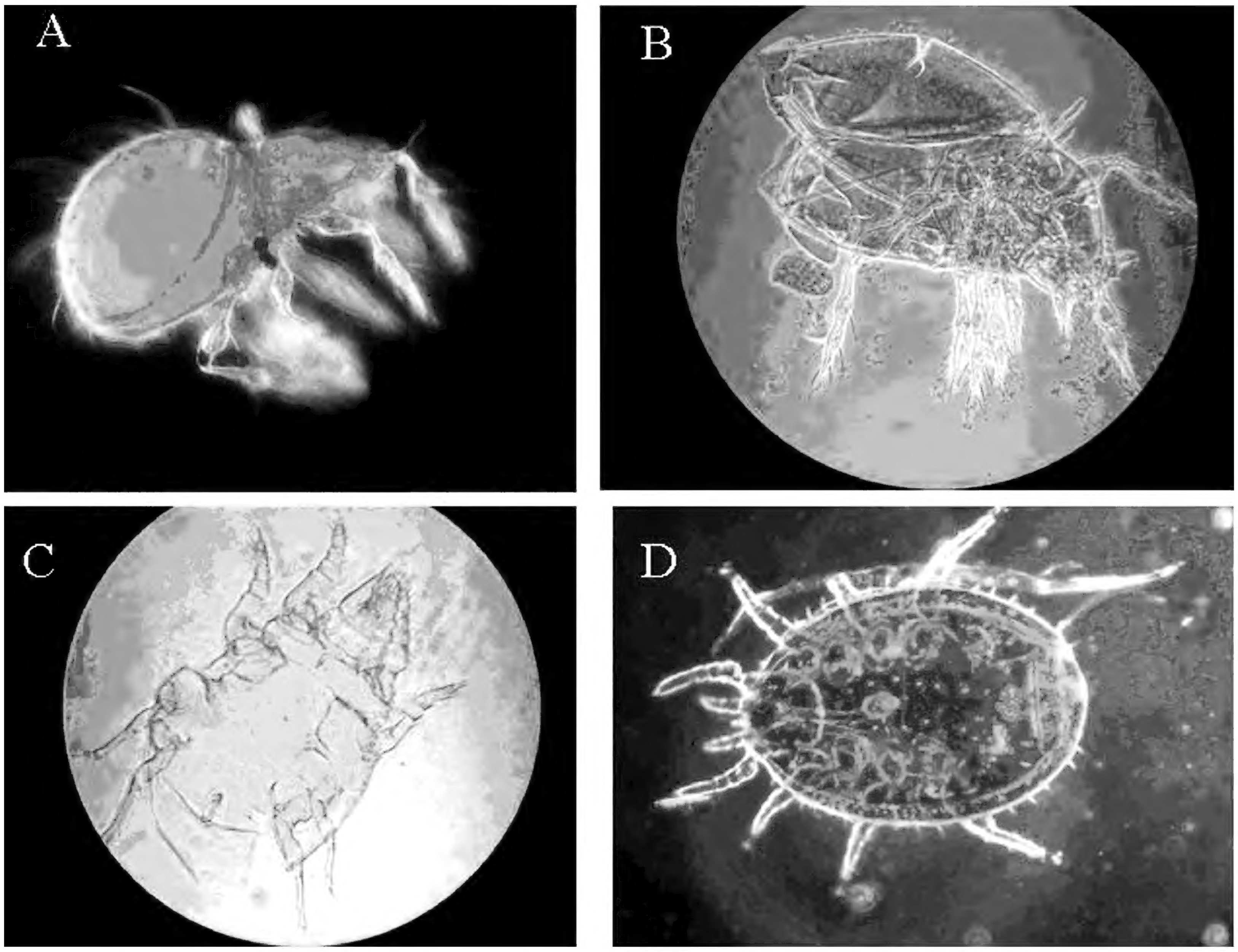


Fig. 3 - Mites found at Las Sardinas cave. A. Cryptostigmata: Oppidae; B. Cryptostigmata: Scheloribatidae; C. Astigmata: Histiostomidae; D. Mesostigmata: Uropodidae.

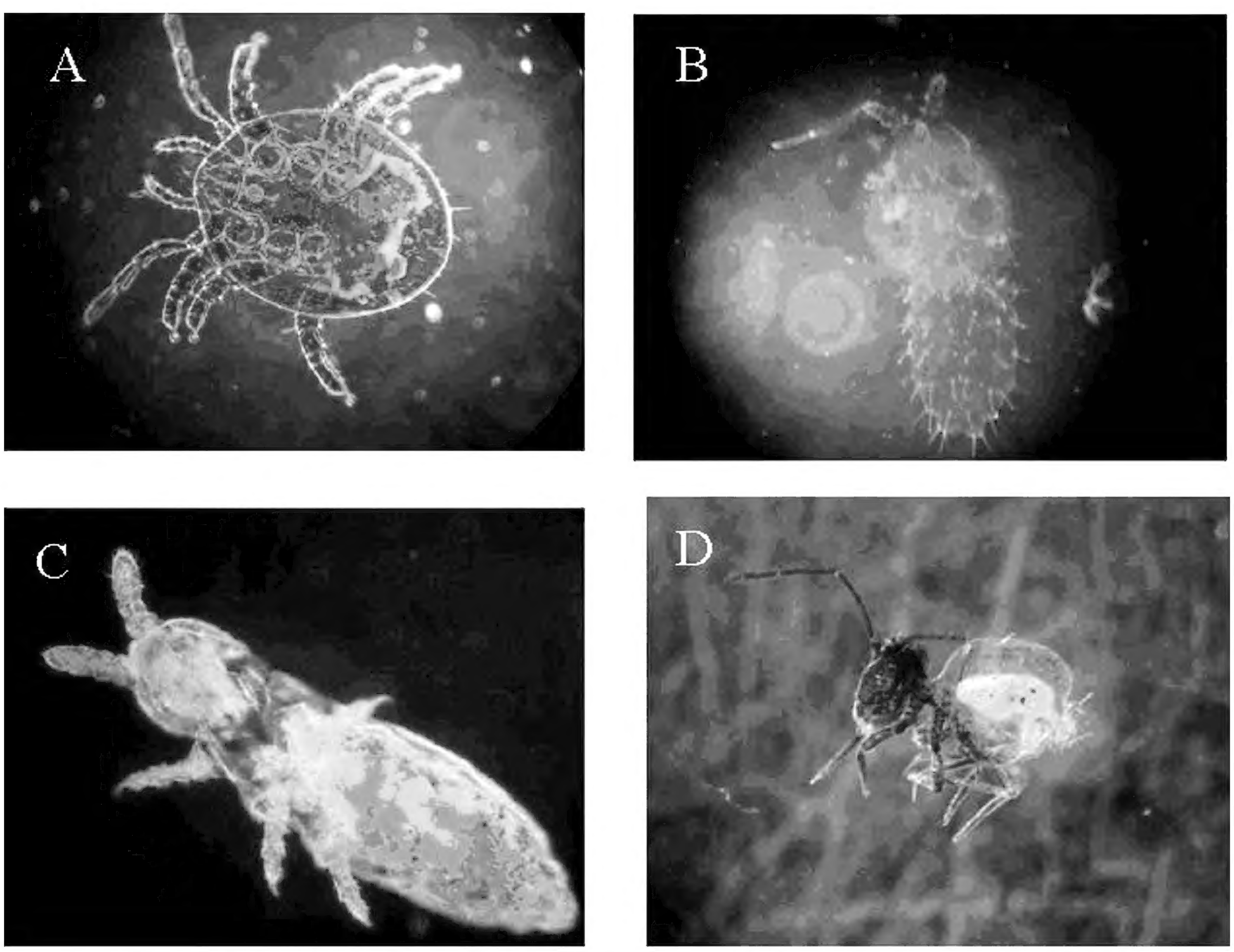


Fig. 4 - Mites and springtails from Las Sardinas cave. A. Mesostigmata: Uropodidae; B. Collembola: Neanuridae; C. Collembola: Hypogastruridae; D. Collembola: Dicyrtomidae.

Table 4 - Results of paired t test between diversity indices. Degrade freedom in parenthesis *p<0.05

| Biotope | Soil under Bacteria | Soil control | Litter | Bat guano |
|---|---|---|---|---|
| Soil under Bacteria | - | 19.54 (597)* | 50.64 (4000)* | 9.65 (2134)* |
| Soil control | 19.54 (597)* | - | 7.63 (547)* | 16.55 (445)* |
| Litter | 50.64 (4000)* | 7.63 (547)* | - | 60.08 (6322)* |
| Bat guano | 9.65 (2134)* | 16.55 (445)* | 60.08 (6322)* | - |

Cluster analysis used to compare the four biotopes in relation to the shared species shows isolation of the litter from the others biotopes. This is the biotope more different in species composition than the others. The other group is grouping the more similar biotopes in the cave and among these the soil under bacteria colonies, and control soil are more similar to each other than the guano (Fig. 5).

The species richness can be explained because of the great diversity of habitats within of Las Sardinas cave. Those habitats together along with other factors such as the vegetation around the cave (Gamboa and Ku 1998), and the connection with the environmental conditions of the area where the cave is located, play an important role in explaining diversity too. The presence of diverse

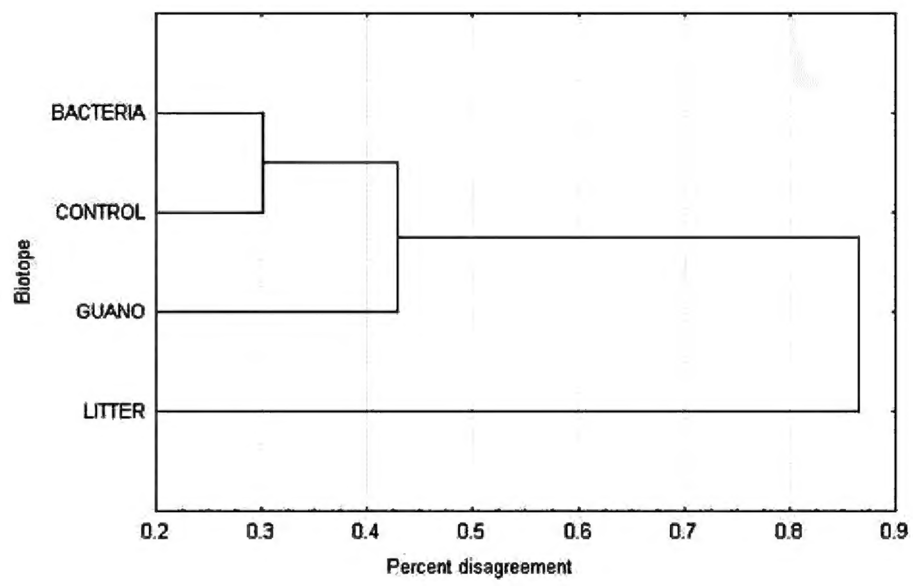


Fig. 5 - Cluster diagram showing the percent of disagreement of the biotopes according with its species composition.

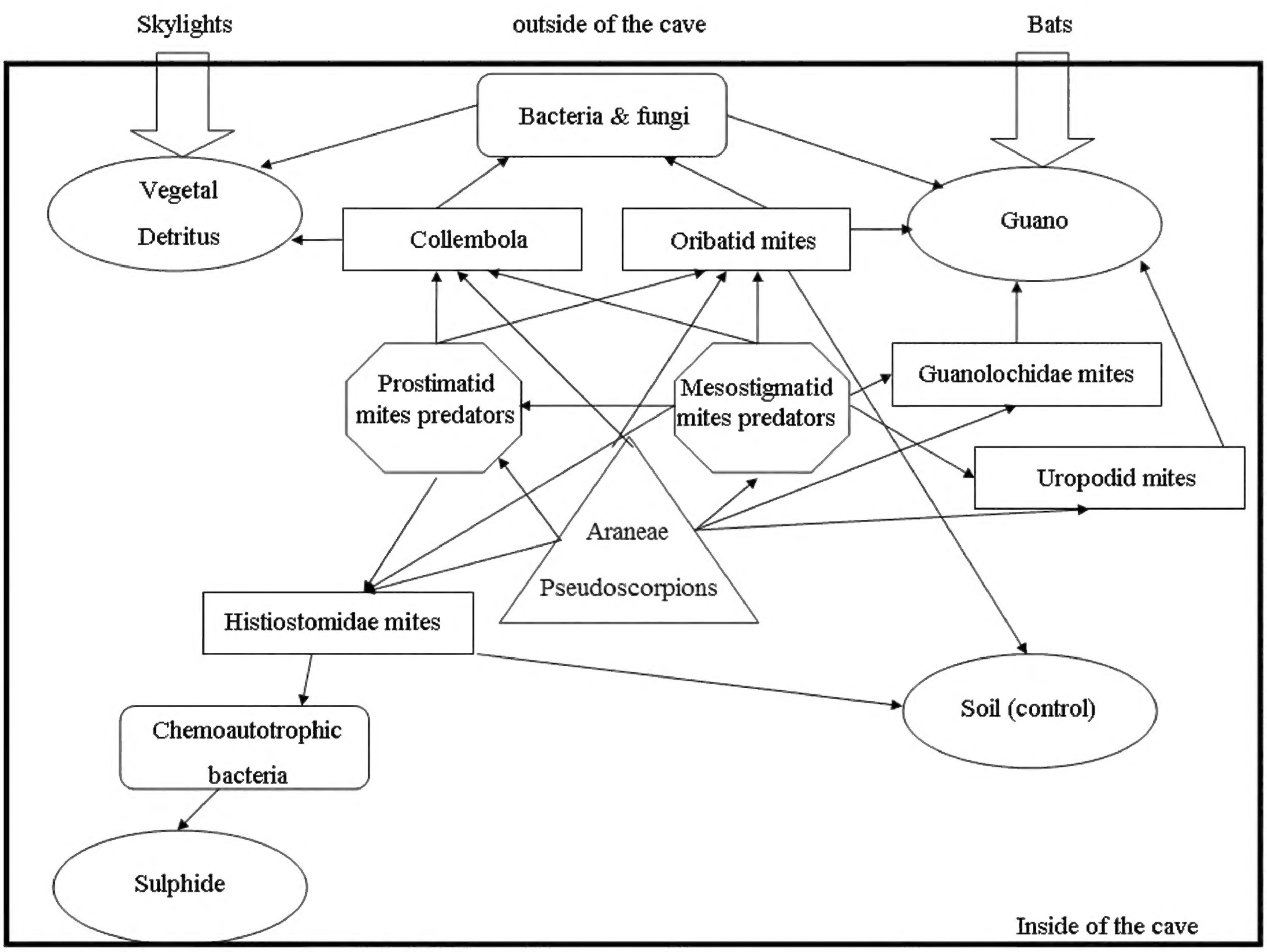


Fig. 6 - Proposed trophic web at Las Sardinas cave, Tabasco, Mexico. = Energy source; = Microorganisms; = Arthropods first consumers; = Arthropods first predators; = Arthropods second predators.

sources of nutrients increases the resources availability that can be exploited by different microarthropods, increasing the possibility to support a diversity of communities. Studies about the diversity of habitats and species richness in caves suggest that, for the terrestrial animals, the local patterns of diversity are very important (Christman and Culver 2001).

Due to the different food resources in Las Sardinas cave, the food webs are very complex. There are four trophic levels which interact, and result in an increase of the energetic fluxes in the system. The main food resources are: plant detritus which come from the surrounding vegetation (Fig. 6). The other important food source is bat guano, and the bacteria colonies are less important. The plant detritus feeds many fungi and some bacteria which are consumed by many Collembola, Oribatid and Uropodid mites, most of them are preys of Prostigmata and Mesostigmata mites, ants, and different arachnids as spiders, pseudoscorpions, amblypygids, and the Scutigerelid centipides. The bat guano contains mites and Collembola very similar to those found at the vegetal detritus, but with some species very specialized as guanophiles.

One important remark is the fact that we found two other species of mormoopid bats *(Pteronotus personatus* and *Pteronotus gymnonotus*) which always form huge colonies. There are also other less abundant species in families Emballonuridae (possible *Baliantopterix*), Phytlostomidae *(Carollia)* and the vampire bat (*Desmodus rotundus* Thomas*)* in subfamily Desmodontinae, additional to the previous recorded species (Gordon and Rosen 1962).

## CONCLUSIONS

This cave is by far the most diverse we have studied, with a least 169 terrestrial microarthropod species. The soil under the chemoautotrophic bacteria and the litter have the lowest value of the diversity index, while the guano has the largest microarthropod abundance. The species found belonging to the families Histiostomidae (Astigmata) and Oppiidae (Crypstostigmata) indicate they have the highest resistance to acid conditions of the environment.

Among microarthropods, the mites are the most abundant group, and Mesostigmata are the dominant group in presence. This result is very different of what is commonly found in the caves, where the springtails are usually the dominant group (Gers 1998). In our results, springtails occupy the sixth place in abundance, after Mesostigmata, Astigmata, Cryptostigmata, Prostigmata and Coleoptera larvae. The presence of many predatory mites suggests that the available resources in the cave can support higher trophic levels.

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